The purely economic case for investing in assistive technology and health in lower and upper-middle income economies

Input-output and network analysis of the assistive technology and health industry ecosystem

Oriol Vallès Codina

Research Fellow in Innovation Policy | UCL Institute for Innovation and Public Purpose

2021 - 2022

Research Fellow in Economics | Leeds University Business School

2022 - present

UCL Institute for Innovation and Public Purpose

WORKING PAPER
WP 2022/13

About the Institute for Innovation and Public Purpose

The UCL Institute for Innovation and Public Purpose (IIPP) aims to develop a new framework for creating, nurturing and evaluating public value in order to achieve economic growth that is more innovation-led, inclusive and sustainable.

We intend this framework to inform the debate about the direction of economic growth and the use of mission-oriented policies to confront social and technological problems. Our work will feed into innovation and industrial policy, financial reform, institutional change, and sustainable development.

A key pillar of IIPP's research is its understanding of markets as outcomes of the interactions between different actors. In this context, public policy should not be seen as simply fixing market failures but also as actively shaping and co-creating markets. Re-focusing and designing public organisations around mission-led, public purpose aims will help tackle the grand challenges facing the 21st century.

IIPP is housed in The Bartlett, a leading global Faculty of the Built Environment at University College London (UCL), with its radical thinking about space, design and sustainability.

This IIPP Working Paper Series is published electronically at https://www.ucl.ac.uk/bartlett/public-purpose/publications/working-papers.

ISSN 2635-0122

This report can be referenced as follows:

Vallès Codina, O. (2022). *The purely economic case for investing in assistive technology and health in lower and upper-middle income economies: Input-output and network analysis of the assistive technology and health industrial ecosystem*. UCL Institute for Innovation and Public Purpose, Working Paper Series (IIPP WP 2022-13). Available at: https://www.ucl.ac.uk/bartlett/public-purpose/publications/working-papers/wp2022-13

The purely economic case for investing in assistive technology and health in lower and upper-middle income economies

Input-output and network analysis of the assistive technology and health industrial ecosystem

Oriol Vallès Codina*

Abstract

As the COVID-19 pandemic has shown, health and assistive technology are not only basic human rights, but also critical for the functioning of all economic activity. Lack of access is especially poignant in low- and middle-income countries, exacerbated after decades of cost-minimising austerity policies narrowly aimed at fixing market failures. In line with the market-shaping, mission-oriented approach to innovation policy, this paper applies input-output and network analysis to India, Iran, Mexico, Philippines, South Africa, Ukraine and Uzbekistan to highlight, especially in the upstream channel, the immediate positive spillovers in output, employment, public revenue and productivity of investing in health and assistive technology, and inducing positive demand shocks rippling throughout the whole of the economy by way of the economic interdependencies in the production of intermediate goods. Contrary to their conventional view as unimportant or peripheral industries, these are in fact integral, well-connected and similar to most sectors of the industrial ecosystem, as input-output production features a very hierarchical network structure with few central hubs catering to a wide range of downstream industries producing final goods.

Keywords: health, assistive technology, market-shaping, developing economies, SDGs, input-output analysis, network analysis

JEL codes: C67, I11, I15, L16, O20, O25, O57, R15

Acknowledgments:

This research is part of AT2030, a programme funded by UK Aid and led by the Global Disability Innovation Hub which is testing 'what works' to improve access to life changing assistive technology. More information at AT2030.org.

* Research Fellow in Economics at Leeds University Business School. Contact: o.vallescodina@leeds.ac.uk

1. Introduction

Complete physical, mental, and social well-being, that is, health, is a fundamental human right, as well as the third UN Sustainable Development Goal - to be guaranteed by universal health coverage. The severe economic and health crisis provoked by the ongoing COVID-19 pandemic demonstrates that unless global health systems are governed for the common good, many people will remain excluded from their benefits, exacerbating existing inequalities in the form of precarious income insecurity, and underfunded and stretched health systems after decades of austerity policies narrowly aimed at minimising costs and fixing the failures of the market (WHO 2021). Yet the COVID-19 pandemic revealed that there is no trade-off between investing in our health systems and economic growth (Smith et al 2020; UNIDO 2021). Instead, health and the economy are, in fact, fundamentally interdependent: not only is health in itself a key economic sector, but it is also a crosscutting issue underlying all economic activity, with a special emphasis on the basic performance of labour that is essential for the economy (UNIDO 2021; WHO 2021). For the WHO Council on the Economics of Health for All, 'Health is critical to the resilience and stability of economies and societies worldwide' (WHO 2021).

Both for-profit commercial initiatives and charitable efforts led by non-profit organisations are unfortunately insufficient to deliver health for all and its substantive economic benefits (WHO 2021). In this context, policy-makers are increasingly embracing market shaping: the idea of using industrial and innovation policy to tackle the 'grand challenges' facing modern societies, among which the transition to a low-carbon economy and health for all are the most critical (Mazzucato 2018; Kattel et al 2018). Designed to be transformative, market shaping aims to reduce long-term demand and supply imbalances, reduce transaction costs and increase market information in line with a unified strategy engaging all stakeholders (Lin and Wilson 2014). A market-shaping role for policy would enable shifting not only the rate, but also the direction of economic growth, namely towards broader notions of public value creation driven by public purpose instead of private profit (Kattel et al 2018). Market shaping has been successfully implemented in a variety of contexts, including global health, which highlights its potential for assistive technology (AT). However, conventional policy evaluation frameworks based on cost-benefit analysis are poorly suited to capturing the dynamic, transformative effects of market-shaping industrial policy in the health sector, especially in developing economies (Kattel et al 2018; Albala et al 2021).

Under the market-shaping view, investment — either public, private or non-profit — must be oriented in the long run towards the grand challenges that modern societies face today: an ATscale report found that sustained provision of AT in low- and middle-income economies has a significant effect on lifetime earning potential, leading to a 9:1 return on investment in the form of USD 10 trillion in economic benefits over the next 55 years (ATscale 2020). This paper focuses instead on the short-term economic benefits of investing in AT and health industries, by applying input-output analysis of their industrial ecosystem within seven lower- and upper-middle income economies (India, Iran, Mexico, Philippines, South Africa, Ukraine and Uzbekistan) to show through their economic multipliers that the returns of mission-oriented investment are in fact immediate, involving rapid positive spillover effects in public revenue, output, employment and productivity in the short run, as well as deep structural changes to the economy that push it towards public purpose. The network structure of input-output production is also evaluated, highlighting the common hierarchical community structure of input-output production, with AT and health industries belonging to the largest components, despite their small output.

In agreement with the industrial policy logic at the basis of the market-shaping view, this paper finds strong empirical evidence in support of large-scale, mission-oriented investment into the upstream channel of the assistive-technology and health value chains, as their output multipliers are much higher in the upstream channel (i.e. as customers of intermediate goods) than downstream (i.e. as suppliers of intermediate goods), rippling through almost all industries (between 75% and 99% of the whole economy). For instance, the total output multiplier of investment per year can be as high as 307% for the production of hearing aids and ophthalmic goods in India, implying that for each dollar invested an extra 2.07 are gained; for wheelchairs, this number is 267%, in contrast to the average of 209%. In terms of employment, Mexican multipliers for eyeglasses and hearing aids are between 1.5 and 1.67 times greater than the average. Contrary to their conventional view as unimportant or peripheral, health and AT industries are in fact as integral, well connected and similar to most sectors of the industrial ecosystem, with an average network centrality, and output and employment multipliers.

2. The case for market-shaping of assistive technologies

2.1 Background

In order to properly deliver health for all, AT is critical. AT is an umbrella term covering the products and services related to the delivery of assistive products such as wheelchairs, eyeglasses, hearing aids, prostheses, digital devices and software (Savage et al 2021). Global commitments, such as the UN Convention on the Rights of Persons with Disabilities, recognise it as a human right. Lack of access to basic assistive technologies excludes individuals from society, reduces their ability to live independent lives and is a barrier to the realisation of the UN Sustainable Development Goals, which vow 'not to leave anyone behind' (MacLachlan et al 2018). Yet 10% of the one billion people who require a particular assistive product or service (wheelchairs, eyeglasses, hearing aids…) do not have access to it, a lack which is especially poignant within low- and middle-income countries (Albala et al 2021). This unmet need for AT is driven by a lack of awareness of the need, discrimination and stigma, a weak enabling environment, lack of political prioritisation, limited investment, and market barriers on the demand and supply side. By 2050, this need is expected to double, due to ageing global populations, increased prevalence of non-communicable diseases and other factors (ATscale 2020).

Current AT delivery practice has been historically shaped by a long-lasting understanding that it provides optional aid for markets that fail to deliver to those in need, emphasising health and social needs while glossing over their potentials for innovation (Albala et al 2021). AT provision in many countries, particularly low- and middle-income countries, has traditionally been conducted in a highly fragmented, erratic and uncoordinated fashion, with limited public funding, donations from charitable organisations and small-scale local providers, and products of varying quality manufactured at a limited price range (Savage et al 2021; ATscale 2020). Insufficient demand

and a low-income base lead investors to view a market as not viable, and therefore they fail to enter or withdraw from the market, while too much demand with too few suppliers can lead to shortfalls and reduction in quality and reliability. This 'market trap' can only be overcome with a vigorous market-shaping policy (MacLachlan et al 2018).

As noted by Mazzucato, Kattel and others (Mazzucato 2015, 2018; Kattel et al 2018), instead of adopting a cost-minimising 'austerity' view of the economic impact of AT investment, a better focus would emphasise its market-shaping properties, i.e. how the creation and production of an entire AT resource chain can provide numerous employment opportunities and innovation spillovers that will readily recover initial investment cost. By proposing a public sector-led mission-based approach, Albala et al highlight how assistive products and services need to be framed globally as essential devices that can enable human capability, create new economic activities and employment, and reduce financial burden on the care system (Albala et al 2021). Targeting market shortcomings that constrain the availability of assistive products and services through mission-oriented, market-shaping investment is proposed to address the root causes limiting availability, affordability and access to appropriate AT, with the wider aim or grand challenge of ensuring improved social, health and economic outcomes for people in need of AT (Albala et al 2019).

After careful analysis of the market landscape and its barriers, successful market-shaping interventions can play a role in enhancing market efficiencies, improving information transparency, easing supply bottlenecks, and coordinating and incentivising the many stakeholders engaged in both demand- and supply-side activities as consumers, procurers, producers, policy-makers and communities (Mazzucato 2018; Kattel et al 2018). Examples of market-shaping, mission-oriented interventions include pooled procurement, de-risking demand, bringing lower cost and high-quality manufacturers into global markets, establishing differential pricing agreements, and improving service delivery by targeting supply chain bottlenecks. These interventions are catalytic and time-bound, with a focus on sustainability, and are implemented through the provision of support from a coalition of aligned partners, each of whom has comparative advantages (Albala et al 2019).

2.2 Examples

Market shaping has been successfully implemented in a variety of contexts, including global health. Mission-oriented market shaping has addressed large-scale market barriers, through USAID efforts to reduce the cost of antiretroviral drugs for HIV by 99% in ten years, increase the number of people receiving malaria treatment, or double the number of women receiving contraceptive implants in four years, while saving donors and governments $240 million (Lin and Wilson 2014; Kejariwal et al 2019; Savage et al 2019). With support the US President's Emergency Plan for AIDS Relief (PEPFAR), the UK Department for International Development (DFID), the Clinton Health Access Initiative (CHAI) and others, South Africa helped cut the cost of antiretrovirals for HIV treatment by more than 70 percent, saving an estimated USD 1 billion by undertaking careful analysis of the market landscape, reaching out to suppliers in India and China to increase supplier competition, enabling procurers to negotiate better prices, incentivising timely delivery and improving transparency (Lin and Wilson 2014). By pooling resources and purchasing healthcare products through a non-profit organisation, such as the Global Alliance for Vaccines and Immunizations (GAVI) or the United Nations International Children's Emergency Fund (UNICEF), governments can reduce production costs and facilitate faster delivery from manufacturers, who may then invest in larger-scale production (Herlin and Pazirandeh 2012).

In a similar direction, the UK Foreign, Commonwealth and Development Office (FCDO) aid-funded inclusive infrastructure sub-programme, AT2030, undertook a four-month research case study on the current state of inclusion and accessibility in the built environment and infrastructure of the city of Varanasi, India (Patrick et al 2021). By engaging communities, policy-makers, industries and non-profits, the study was able to identify the pressing need for a coherent industrial strategy among all stakeholders, arguing for the market-shaping potential of inclusive design as a grand challenge (Patrick et al 2021). By conducting in-depth interviews with the major stakeholders involved in policy, acquisition, procurement, production and distribution of assistive products in Mongolia, a similar AT2030 study was able to assess the country's AT capacity, identifying key challenges and opportunities, as well as providing lessons and insights on strategic objectives for policy-makers to deliver coherent market-shaping policy that addressed the AT needs of the country (Deepak 2019).

Building on the success of the Innovate Now Accelerator in Nairobi, Kenya, Africa's first AT accelerator, AT2030 launched the Assistive Tech Impact Fund project, the world's first investment vehicle dedicated to testing and evaluating local solution models with the potential to scale up AT innovations in emerging markets (Simpson et al 2021). The project, funded by UK Aid and led by the Global Disability Innovation Hub, provides grant funding as well as customised business, research and technical support to pioneering AT innovators working towards increasing AT access to millions of AT users across Africa, pushing the boundaries of AT innovation and disrupting the archaic models of AT production and supply in the African market. Key insights from the first cohort of AT ventures emphasised the need to provide an adequate enabling environment to reduce the burden on innovators, the pioneering scope of the venture business models in the sector, the predictability of scaling pathways under catalytic cash injections, the steady emergence of new playbooks tailored for the needs of each AT market, and the development of new and novel payment solutions that enable customers to pay for their AT needs (Simpson et al 2021).

2.3 Need for new accounting frameworks

While the shift towards mission-oriented industrial policy is becoming more tangible over time, a key question is whether existing policy tools, ranging from conceptual frameworks to evaluation methodologies and data analytics, enable or rather constrain such a transformation (Kattel et al 2018). Driven by a cost-minimising austerity approach narrowly focused on fixing market failures, current public policy discussions often start from existing fiscal constraints limiting state capacity, instead of policy goals and desired outcomes driven by public purpose whose implementation may even enhance state capacity (Kelton 2011). In contrast, mission-oriented industrial policy emphasises its transformative scope to shape the market; in particular, it considers how investment, either in the form of government or private spending, may induce well-defined autocatalytic ripple effects on output, employment, productivity and public revenue, through existing economic interdependencies in consumption and production, which not only enable growth to increase at a faster rate than borrowing (hence reducing the debt-to-GDP ratio), but also shift the direction of economic structural change and orient the market economy towards more public notions of value.

However, given their static, equilibrium view of market processes and their failures, conventional policy evaluation frameworks guided by constraint-driven budgeting (such as cost-benefit analysis) are poorly suited to capturing the dynamic, transformative effects of market-shaping industrial policy (Kattel et al 2018). By comparing the policy intervention to the status quo and emphasising short-term risks, cost-benefit analysis encourages decision-makers to prefer small-scale, marginal interventions (Allas 2014). However, mounting empirical evidence highlights the increasing returns and positive spillovers of investment on innovation systems, supporting instead large-scale interventions in industrial policy (Romer 1986; Silverberg et al 1988; Krugman 1991; Grossman and Helpman 1993; Krugman 1998; Dosi et al 1999; Mazzucato and Macfarlane 2017). In this direction, analytical frameworks emerging out of evolutionary economics (Schumpeter 1942; Alchian 1950; Nelson and Winter 1974, 1978; Becker et al 2006; Nelson and Winter 2009), systems thinking (Forrester 1970, 1971, 1997; Meadows et al 2004; Turner 2008) and complexity economics (Durlauf 1993; Arthur et al 1994, 1997; Arthur 1999, 2014; Foley 2003, 2005; Beinhocker 2006) already have a long history in emphasising the economic relevance of reinforcing and balancing feedback effects of non-linear dynamical processes, subject to increasing returns, network complementarities, fundamental uncertainty, path dependence, complex emergence and a lack of optimality that altogether drive transformative, structural change in a complex, adaptive, self-organising economy, which conventional static, equilibrium approaches simply cannot capture.

Despite such theoretical and empirical issues, pre-existing conventional evaluation frameworks based on cost-benefit analysis most importantly highlight the significantly positive economic impact of investment on AT in developed economies in the form of costs saved to the health and social care systems, compared to profit/value added or cost-recovered (Drummond et al 1993; Andrich et al 1998; Drummond et al 2015): these studies generally find that the usage costs of AT, based on historical, modeled or recently collected data, are lower than standard care costs (Albala et al 2021). However, such studies are poorly suited to capture the value that arises from AT service delivery, access and user interactions (Albala et al 2019). As noted by Fuhrer (2001), such cost assessments may be problematic as the economic perspective of cost can greatly vary depending on the perspective taken by patients, insurers, providers or wider society. Further, a pressing issue when reviewing the available evidence of cost-effective assessments of AT is its global applicability, since it is very difficult to extrapolate to developing economies with very different health systems (Albala et al 2019, 2021). A model based on how AT provision may result in fewer hospital admissions or a decrease in house aid hours (and thus reduce health costs for governments) may not be a strong argument for developing countries that do not have the same health and care infrastructures that already supply the social and care nets of developed economies (Albala et al 2019).

Under the market-shaping view, consideration of the whole health innovation chain within its own industrial ecosystem, from initial production to the user experience, and how AT enables human capability and functioning, should be the framing going forward to accurately capture how investment in health industries may bring about economic, individual and societal growth (Albala et al 2019; Boggs et al 2021). In this direction, the following section details how the theoretical and empirical framework of input-output analysis is particularly well-suited for characterising the structure of the industrial ecosystems of particular sectors and thus capturing the dynamic, transformative, positive effects of investment on health, either upstream or downstream, in the form of industry-level output and employment multipliers.

3. Aggregate and sector-level multipliers

3.1 Aggregate multipliers: the consumption channel

Economic multipliers arise due to the interdependencies that exist between industries and consumers at the level of investment, consumption and production activities. Their actual size at the aggregate level corresponds to one of the most contested debates of macroeconomic theory and empirical analysis between Keynesian and monetarist perspectives (Blanchard and Leigh 2013; Deleidi et al 2020). At the aggregate level, additional spending may increase or decrease aggregate output through the consumption channel, scaling production, employment and productivity up (crowding in) or down (crowding out), depending on whether the multiplier is above or below one. As Keynes famously noted, government spending and the resulting employment it creates will stimulate several almost instantaneous rounds of spending through consumption, thus raising effective demand and investment, and creating further employment through a self-enforcing circular process (Kahn 1931; Keynes 1936). Because producers are also consumers, a government dollar that is injected into the economy may circulate many times and be exchanged by many hands before it is saved, so that the economic multiplier will be larger than one.

The national account decomposes in the aggregate the gross output of a closed economy into consumption, investment and government spending, where consumption can be written as output multiplied by the marginal propensity to consume c:

$$Y = C + I + G = cY + I + G \tag{1}$$

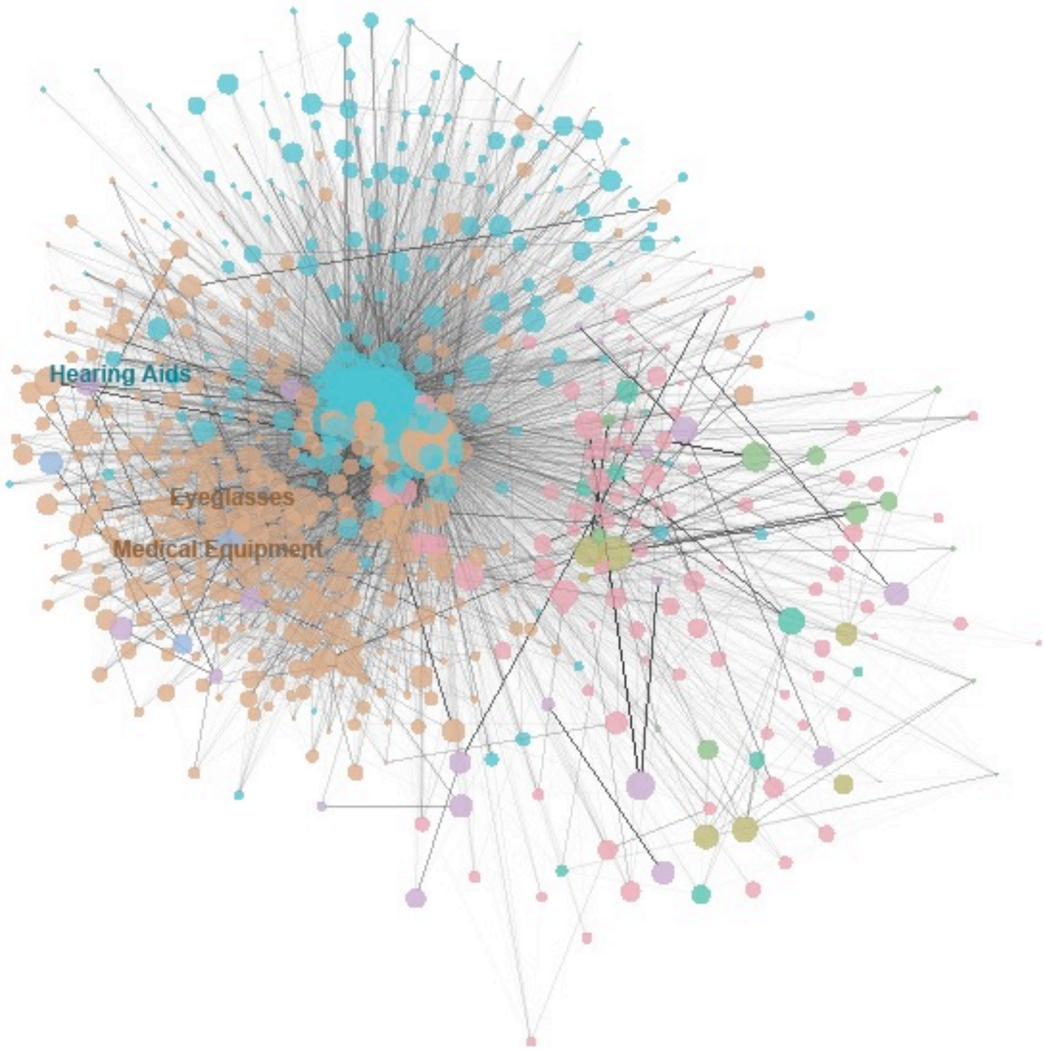
By isolating output *Y*, one easily obtains the aggregate economic multiplier *m*, to be estimated empirically:

$$Y = \frac{I + G}{1 - c} = m\,(I + G) \tag{2}$$

where $m = (1 - c)^{-1}$. Note that the multiplier applies both for public spending and private investment alike, without distinction. In contrast, the monetarist view supports the Ricardian equivalence hypothesis and contends that debt-financed government spending will, in fact, crowd out private investment and induce capital inefficiencies, by increasing interest rates and rendering borrowing more expensive, even without full resource utilisation (Friedman 1978; Seater 1993;

Ricciuti 2003). Under this view, fiscal austerity may even be expansive rather than contractionary (Alesina and Ardagna 2010).

Figure 1: Network visualisation of the input-output structure of Mexico

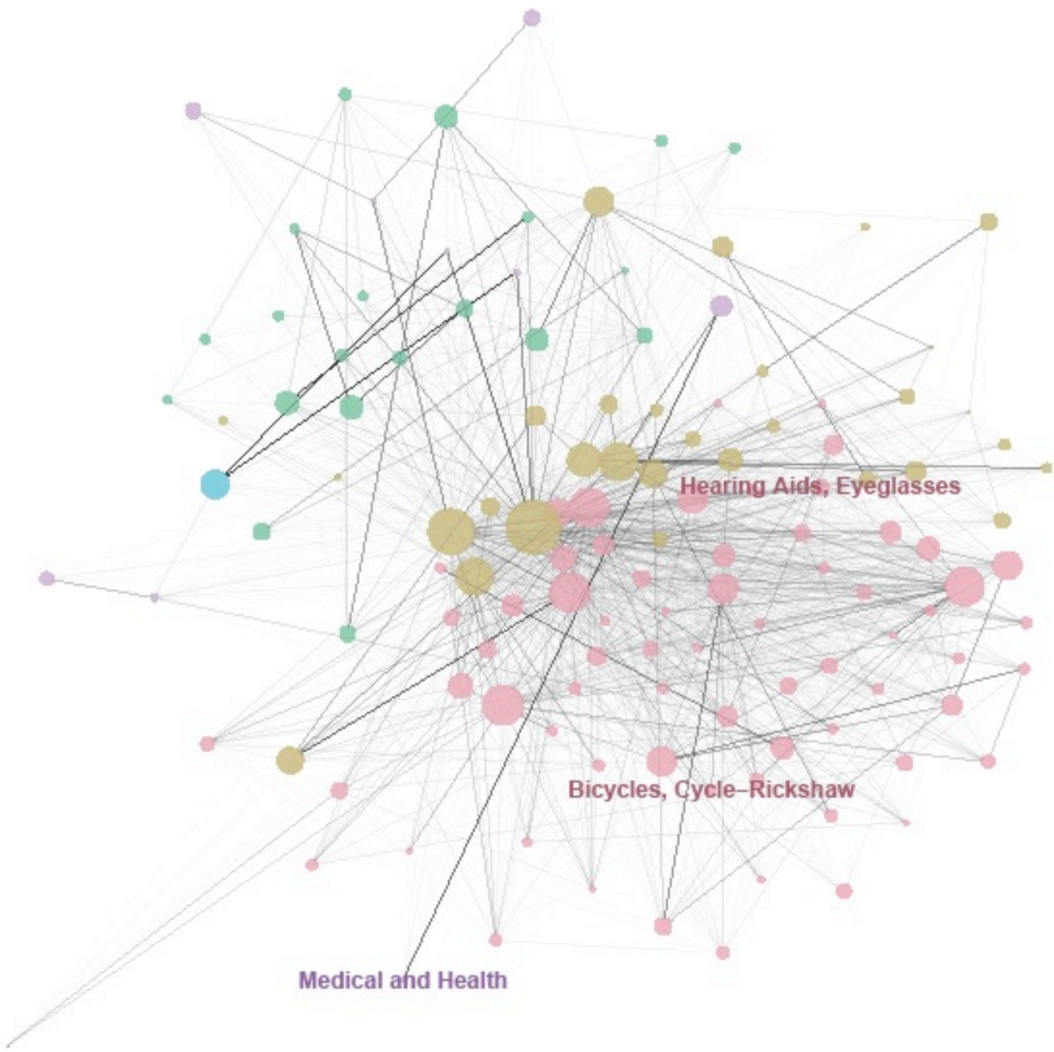


Source: Authors' own illustration

3.2 Industry multipliers: the production channel

Aggregate perspectives treat the structure of the economy as a 'black box' by focusing only on final demand, glossing over industrial demand for intermediate goods. Hence the salient interdependency at such a level of analysis is through Keynesian linkages in consumption, while glossing over the industry linkages in intermediate production that propagate shocks in demand in a similar circular fashion to the consumption channel. At the industry level, input-output analysis (Leontief 1966; Pasinetti 1977; Miller and Blair 2009; Torres-González and Yang 2019) can provide helpful insights on the input-output interdependencies in production that form the actual economic ecosystem of specific industries, namely their location and relevance within the structure of value chains that in the aggregate form the whole of an economy. In this context, additional investments in one industry led to a higher output that can be re-invested in the economy (i.e. direct multiplier, induced investment). As noted by Hirschman (1958), investment may still show important indirect effects through economic interdependencies in production: in this case, the investment in one industry creates a need for investment in other industries. For instance, the investment in a cycle hire scheme calls for investments in bike maintenance and repair, in transport services but also in infrastructure (cycling paths) and so on. In other words, the investment in one industry creates a chain of investments in the whole economy, which input-output analysis is particularly suited to track.

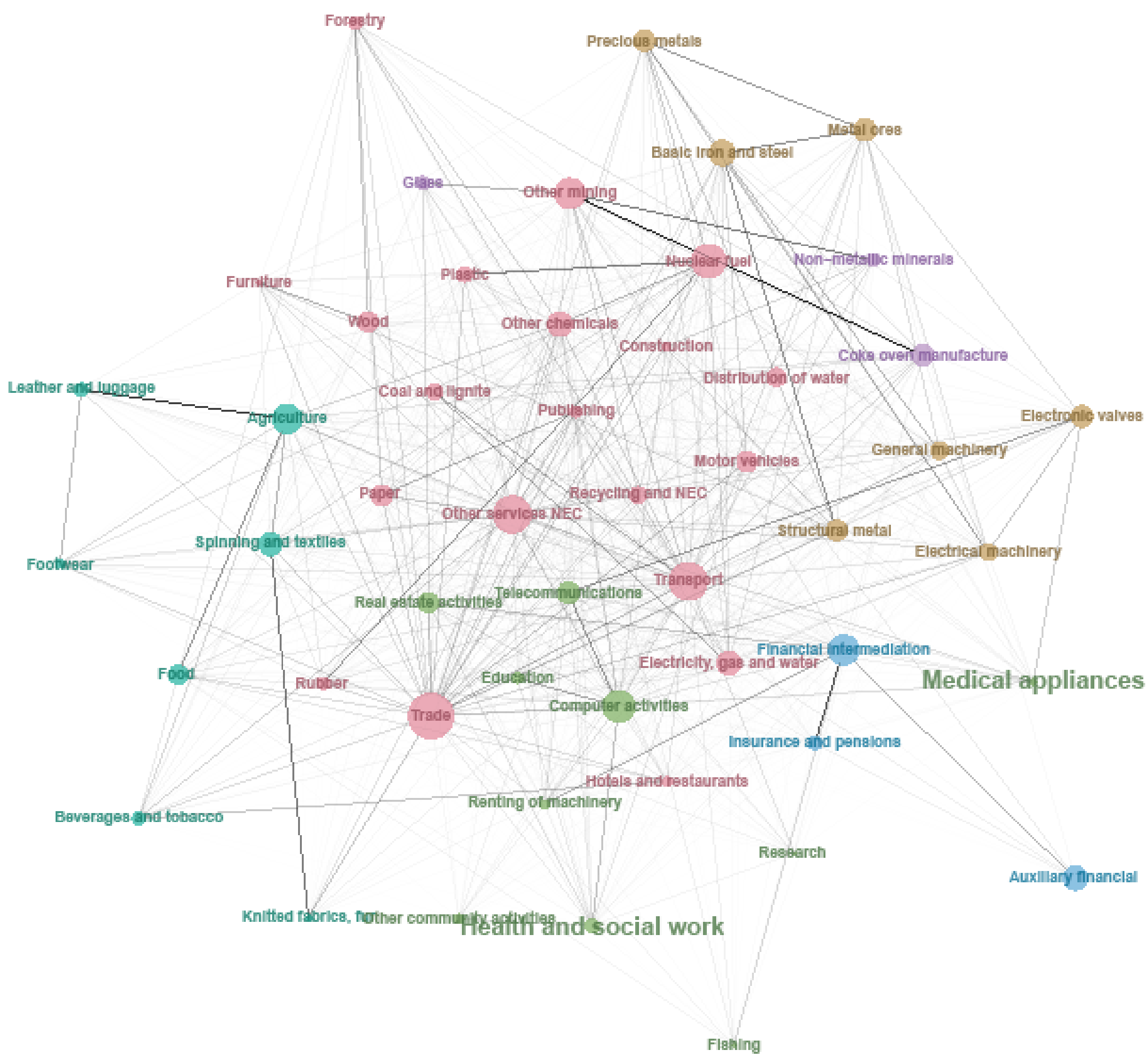
Figure 2: Network visualisation of the input-output structure of India



Source: Authors' own illustration

The chain of transmission can run from user to supplier industries (backward linkages) or from supplier to user industries (forward linkages). In the presence of backward linkages, a variation in final demand in one industry will induce a variation in the production of its supplier industries. For instance, if the demand for computers increases, the industry providing these goods will require more plastic parts and electronics components from its suppliers, among other things. The plastics industry will, in turn, require additional inputs to fulfil the requests of the electronics industry, and so on. In sum, the initial increase in the demand for computers will be transmitted to other industries through the input-output network. A similar inducement mechanism can take place from supplier to user industries through forward linkages. In this case, a shock in supply rather than demand is transmitted across the economic system.

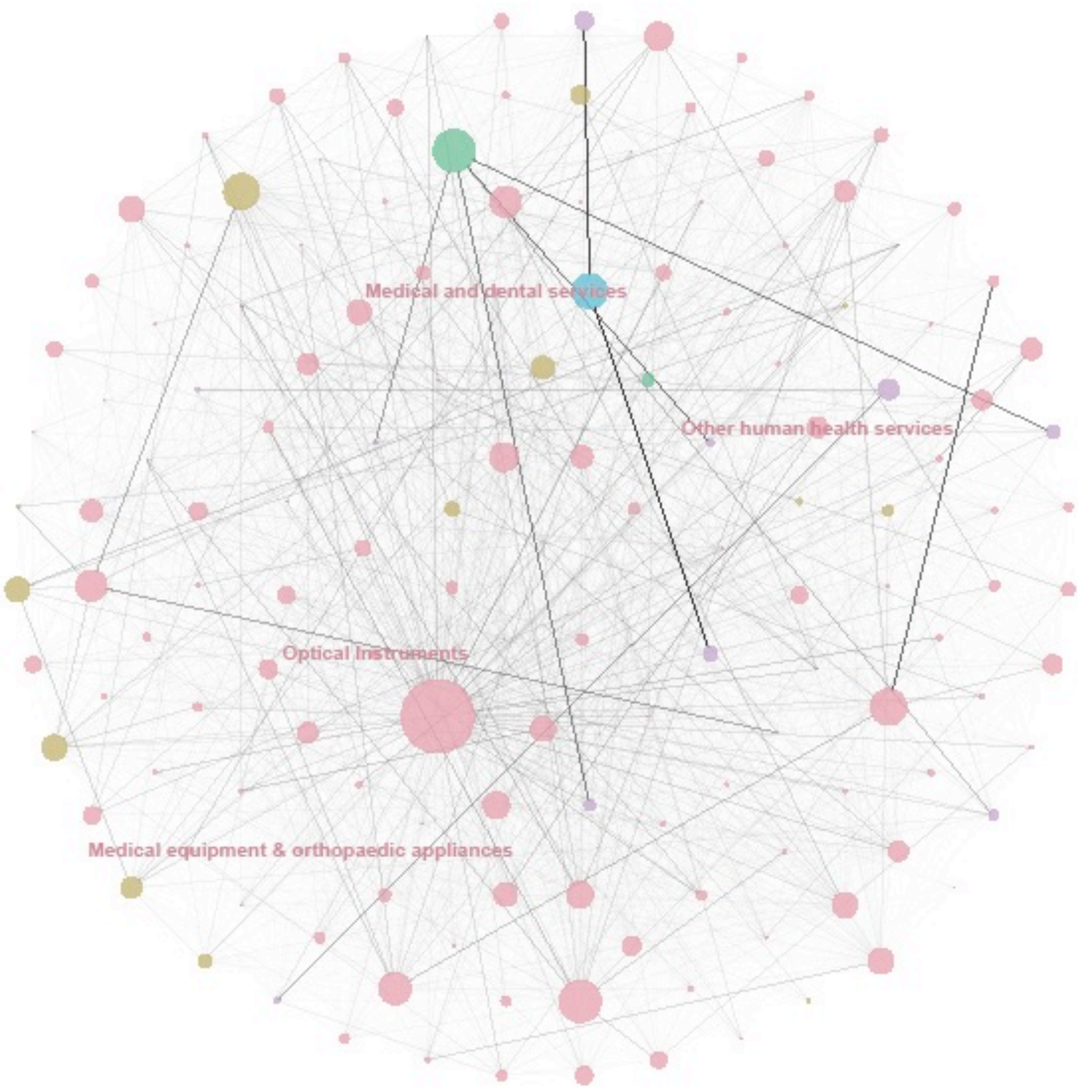
Figure 3: Network visualisation of the input-output structure of South Africa



Source: Authors' own illustration

If health industries are connected via many input-output linkages in production to the rest of the economy, an external increase in their output (induced either by government or non-profit spending, or by fixed investment for profit) implies a positive demand shock for the many other sectors providing their inputs, accelerating capital investment in new machinery and thus technical progress. According to Verdoorn's law, due to the increasing returns to scale of learning-by-doing, labour productivity will also grow with output, which posits an empirical correlation between productivity and output growth of an average of around 0.5 (Verdoorn 1949; Kaldor 1970; Thirlwall 1979; McCombie and de Ridder 1984; McCombie et al 2002; Deleidi et al 2018). Investment in health industries may reverberate in the form of a positive demand shock for intermediate goods to the whole of the economy through the production channel, inducing positive spillovers in output, employment, public revenue and productivity to the industries within the health value chain. On the supply side, investment on health may induce a positive supply shock increasing productivity both for capital and labour, reducing the production costs of such technologies in a way that consumers will immediately benefit, as well as the efficiency costs of industries using such technologies as input.

Figure 4: Network visualisation of the input-output structure of Iran



Source: Authors' own illustration

3.3 Definitions

Input-output tables are square matrices that represent the whole of a national economy for a particular year by documenting the monetary flows between sectors of production (i.e. demand for intermediate goods via input-output linkages in production) as well as final demand, which can include imports and exports for open economies (Leontief 1966; Pasinetti 1977; Miller and Blair 2009).

Table 1: Assistive technology and health industries, selected lower and upper-middle income countries

Mexico	**Iran**
Medical equipment Eyeglasses Hearing aids	Medical equipment, orthopaedic appliances Eyeglasses Medical, dental services Other human health services
India	**Uzbekistan**
Wheelchairs Hearing aids, eyeglasses Medical, health	Medical equipment Medical products Health, recreation
South Africa	**Ukraine**
Medical appliances Health, social work	Medical equipment Medical products Health, recreation
Philippines	
Medical health services	

In the standard Leontief model of a closed economy, the output of industry i, x_i, depends on the demand for intermediate inputs $\sum_j a_{ij}x_j$ from industries j, and for final goods, f_i, which is the sector-level component of final demand, Y:

$$x_i = \sum_j a_{ij}x_j + f_i = \underbrace{\sum_j a_{ij}x_j}_{\text{intermediate demand}} + \underbrace{c_i + i_i + g_i}_{\text{final demand}} \qquad (3)$$

where a_{ij} corresponds to the technical coefficients of the input-output table and x_j the output of other industries that are supplied downstream by industry i. The a_{ij} coefficients can thus be understood as the *direct output multipliers* on industry i immediately induced by the demand for intermediate goods by industries j. Hence, the values of the jth column of the input-output table a_{ij} refer to all ith goods demanded by industry j (Figure 6). Bilateral sector trade balances tb_{ij} (exports minus imports) can also be added in the case of an open (or multi-region) economy.

Equation (3) can be written in matrix notation:

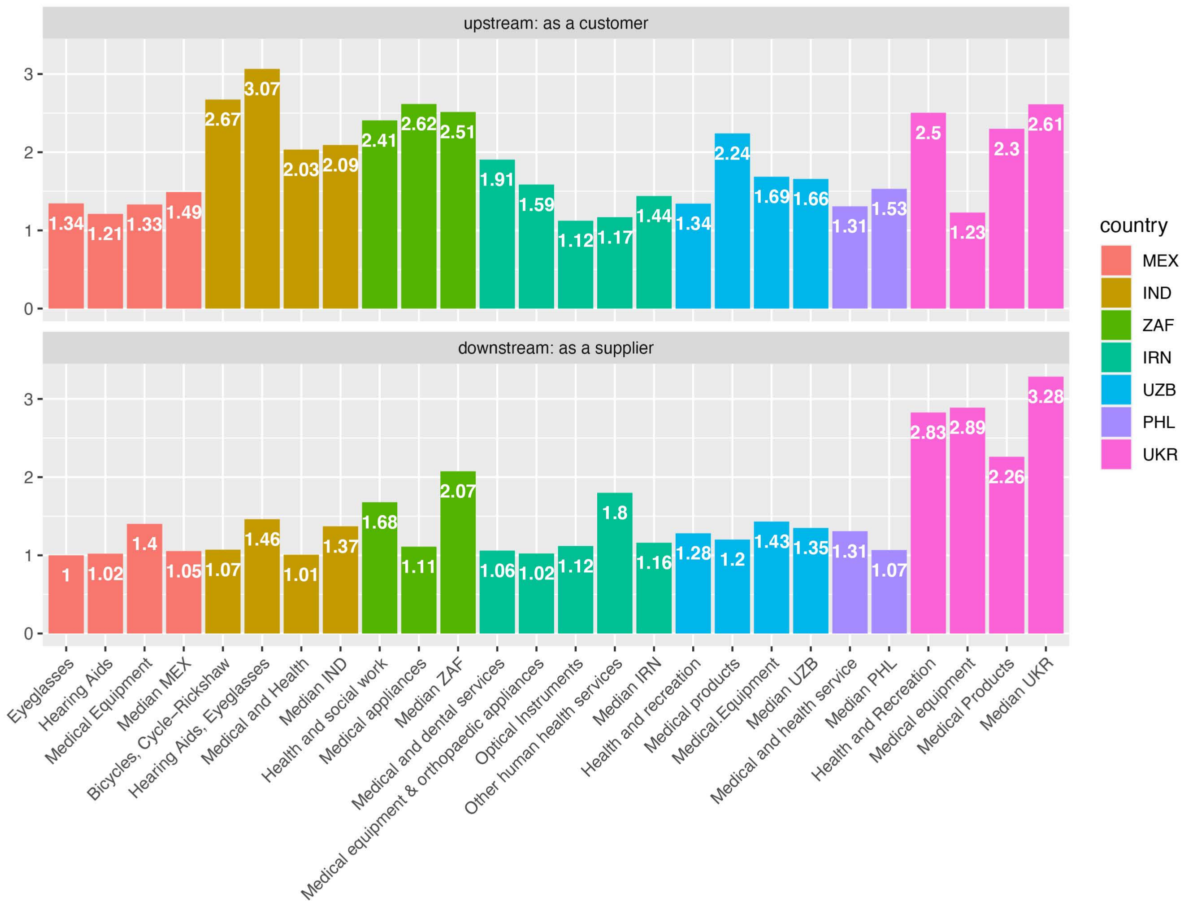
$$X = AX + Y$$

which yields:

$$X = (I - A)^{-1}Y = LY \qquad \text{where } L \equiv (I - A)^{-1} \qquad (4)$$

L is the Leontief matrix of total requirements, which relates the gross output vector X to the surplus vector of final demand $Y = f_i$, of which investment in fixed capital is a component. In contrast, investment in circulating capital $\Sigma_j a_{ij}x_j$, that is, the intermediate goods necessary for the production of all final goods as well as other intermediate goods, as required by the economic structure of interdependent input-output linkages in technology, is not.

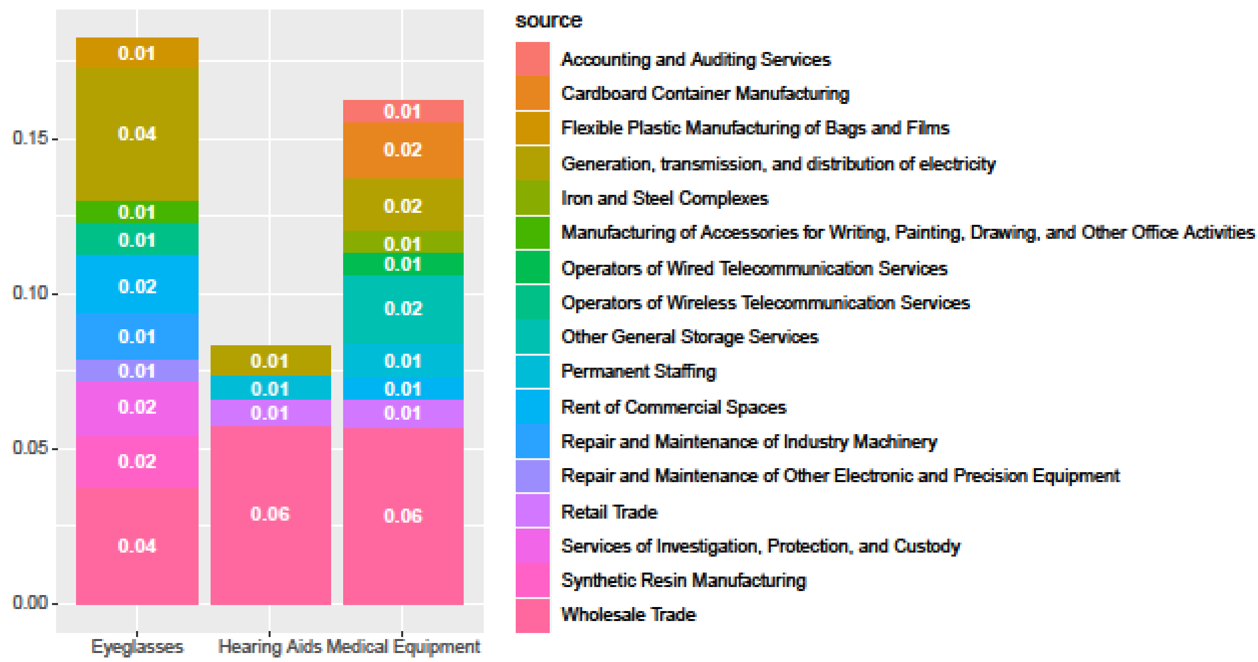
Figure 5: Aggregate Leontief output multipliers



Source: Authors' own illustration

In this context, the Leontief matrix captures how a variation in the output of one industry, induced by a change in its final demand, can affect all industries related to it through their input-output linkages, both directly (as the immediate intermediate goods for production) and indirectly (over the successive intermediate goods required to produce the former). Not only total Leontief multipliers will always be higher than direct multipliers, after subtracting by the own industry contribution of one unit; many industries that are not direct suppliers to a particular sector may still be accounted as indirect suppliers when Leontief multipliers are taken into account.

Figure 6: Upstream direct sector-by-sector multipliers for assistive technologies, Mexico 2013



Source: Authors' own illustration

One can retrieve aggregate gross output Y as in the original equation (1) by summing over all industries i in order to obtain aggregate quantities:

$$Y == \underbrace{\sum_i f_i}_{\text{aggregate demand}} \quad Xc_i + i_i + g_i = Xx_i - Xa_{ij}x_i = X(1 - a_{ij})x_i = Xl_{ij-1}x_i \tag{5}$$

Aggregate demand thus corresponds to the surplus of an economy, i.e. total gross output minus intermediate production. By expanding the inverse L matrix into a power series, one can thus show Keynes' argument in mathematical form regarding the production channel (instead of the consumption channel), by tracking how a new currency unit in circulating investment can thus circulate throughout the economy in many successive time periods, generating positive spillovers on output, employment and value-added:

$$L = (I - A)^{-1} = I + A + A^2 + A^3 + \ldots$$

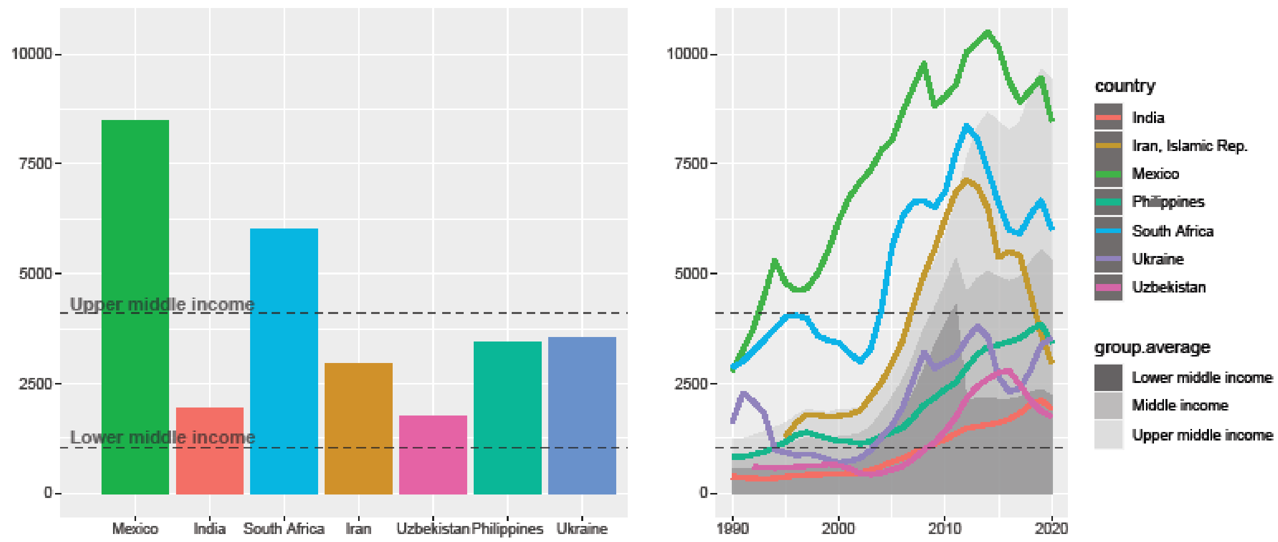
so that equation (4) becomes:

$$X = LF = F + AF + A^2F + A^3F + \ldots \tag{6}$$

showing how the gross output X that is required to produce final goods F is such same quantity of goods F, the intermediate goods AF required to produce final goods F, the (second-order) intermediate goods A^2F required to produce intermediate goods AF, the (third-order) intermediate goods A^3F required to produce (second-order) intermediate goods A^2F, and so on in many successive periods of production until the very beginning of time.

Hence, the Leontief coefficient l_{ij} can be conceived as the *total (direct and indirect) output multiplier* between sectors i and j (Figure 5). The diagonal Leontief coefficients will always be greater than one, since they first include the value of the initial currency unit invested: the actual multiplier effect lies on the extra units above one. In the figures disaggregating the Leontief multipliers by sector, only the actual multiplier effect that spills over other industries is taken into account.

Figure 7: GNI per capita, Atlas method 2020, for selected countries: barplot (left) and time evolution since 1990 (right) (horizontal lines show the minimum threshold to classify as LMIC or UMI economies; shaded areas represent the average)



Source: Authors' own illustration

The aggregate output multiplier is the sum of all particular contributions:

$$\sum_a l_{ij} \qquad a = \begin{cases} i & \text{downstream} \\ j & \text{upstream} \end{cases} \tag{7}$$

$$\sum_a \omega_a l_{ij} \qquad \text{where } a = i, j \text{ and } \omega_a = \frac{\text{employment}_a}{\text{gross output}_a} \tag{8}$$

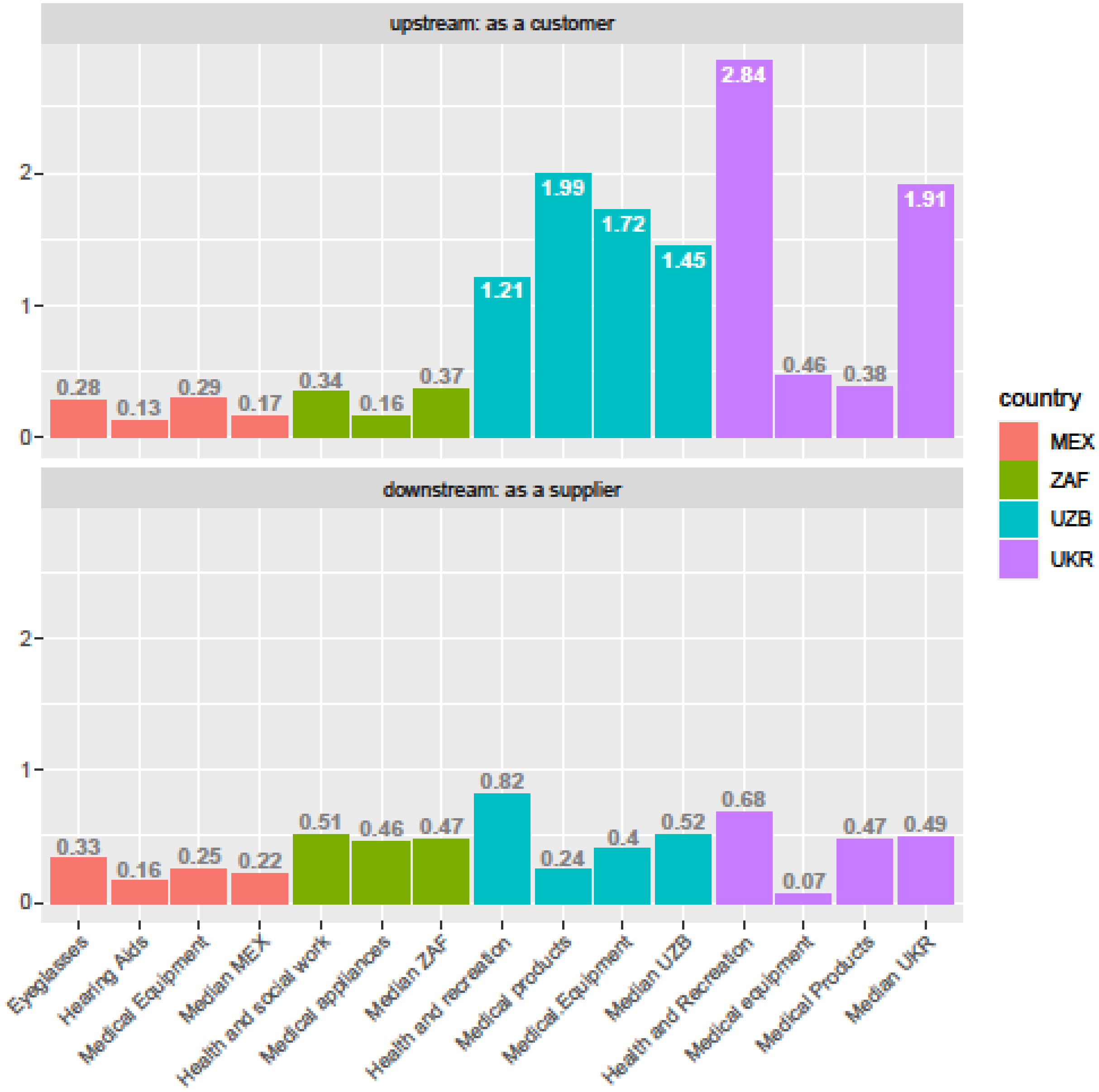
Finally, *value-added multipliers* can be also defined in a similar way:

$$\sum_a \theta_a l_{ij} \qquad \text{where } a = i, j \text{ and } \theta_a = \frac{\text{value-added}_a}{\text{gross output}_a} \tag{9}$$

where the sum can be over rows *i* for the downstream output multiplier (i.e. the relevance of industry *j* as a customer) or over columns *j* for the upstream output multiplier (i.e. the importance of industry *j* as a supplier) (Miller and Blair 2009; Izquierdo Peinado et al 2019). Further, *employment multipliers* can be also computed, either as downstream or upstream, employment:

In this context, multipliers of industrial activities can also be seen as indicators of structural changes in the economy, either for output, employment and productivity (ie value-added).

Figure 8: Worker compensation, aggregate Leontief multipliers

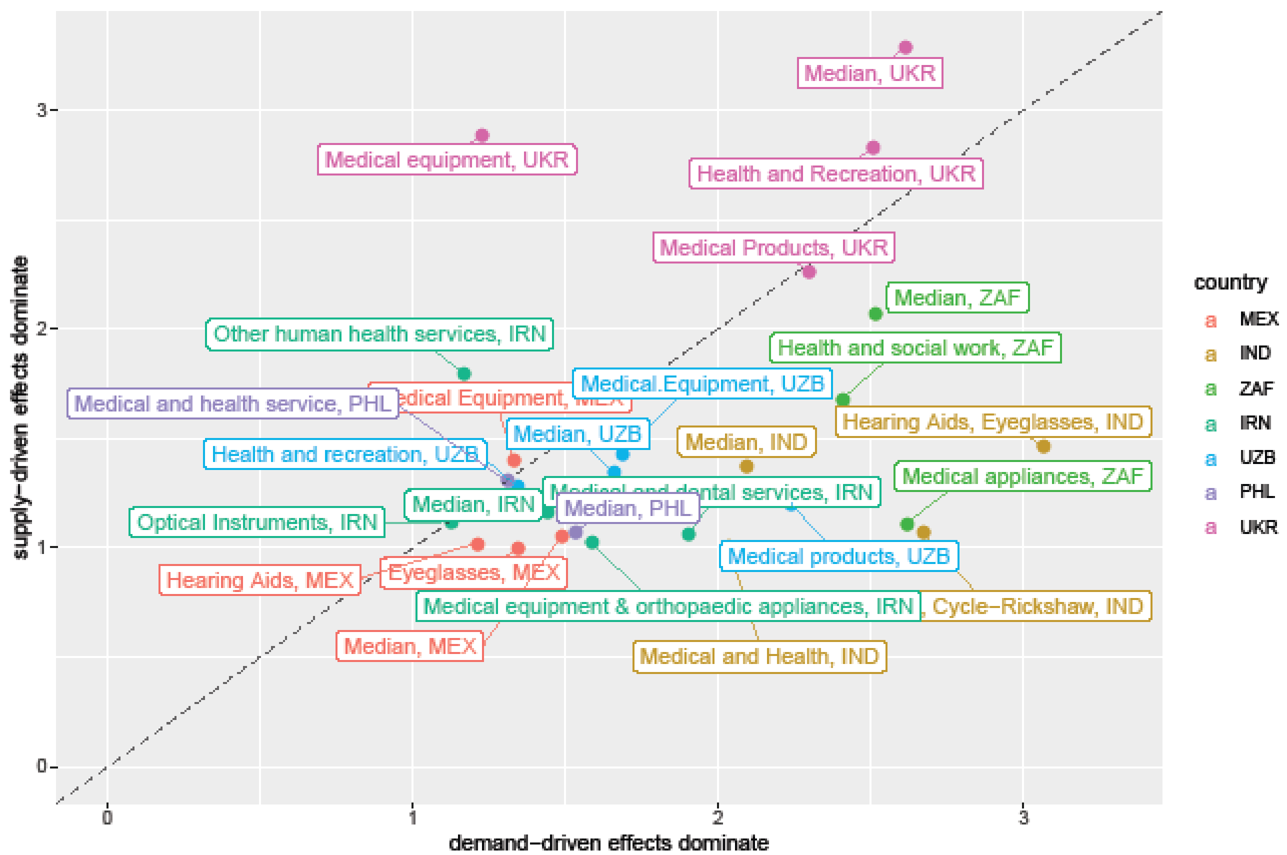


Source: Authors' own illustration

3.4 Multipliers as a measure of network centrality

Input-output tables can be also approached from the perspective of network theory (Blöchl et al 2011; Cerina et al 2015; Foerster and Choi 2017). In this context, the economic sector multipliers can be seen as an indicator of structural change. A network perspective on production linkages and supply chains offers novel insights on the sources of aggregate fluctuations and how they propagate through the industries forming the structure of the whole economy (Acemoglu et al 2012; Carvalho 2014). Under the network-theoretical view, the input-output matrix characterises the production network of a particular economy, where each non-zero entry refers to a linkage in intermediate production, the magnitude of which refers to its weight or intensity in the network. In network-theory terms, it refers to the adjacency matrix of a directed weighted network that is connected via linkages in intermediate production as edges, whose weights are related to the input-output coefficients. Social network analysis proposes many interesting measures that capture the relevance of particular nodes within the whole network, which are directly related to the input-output theoretical framework and thus the output multipliers (Newman 2018).

Figure 9: Absolute returns of spillover effects, upstream vs downstream



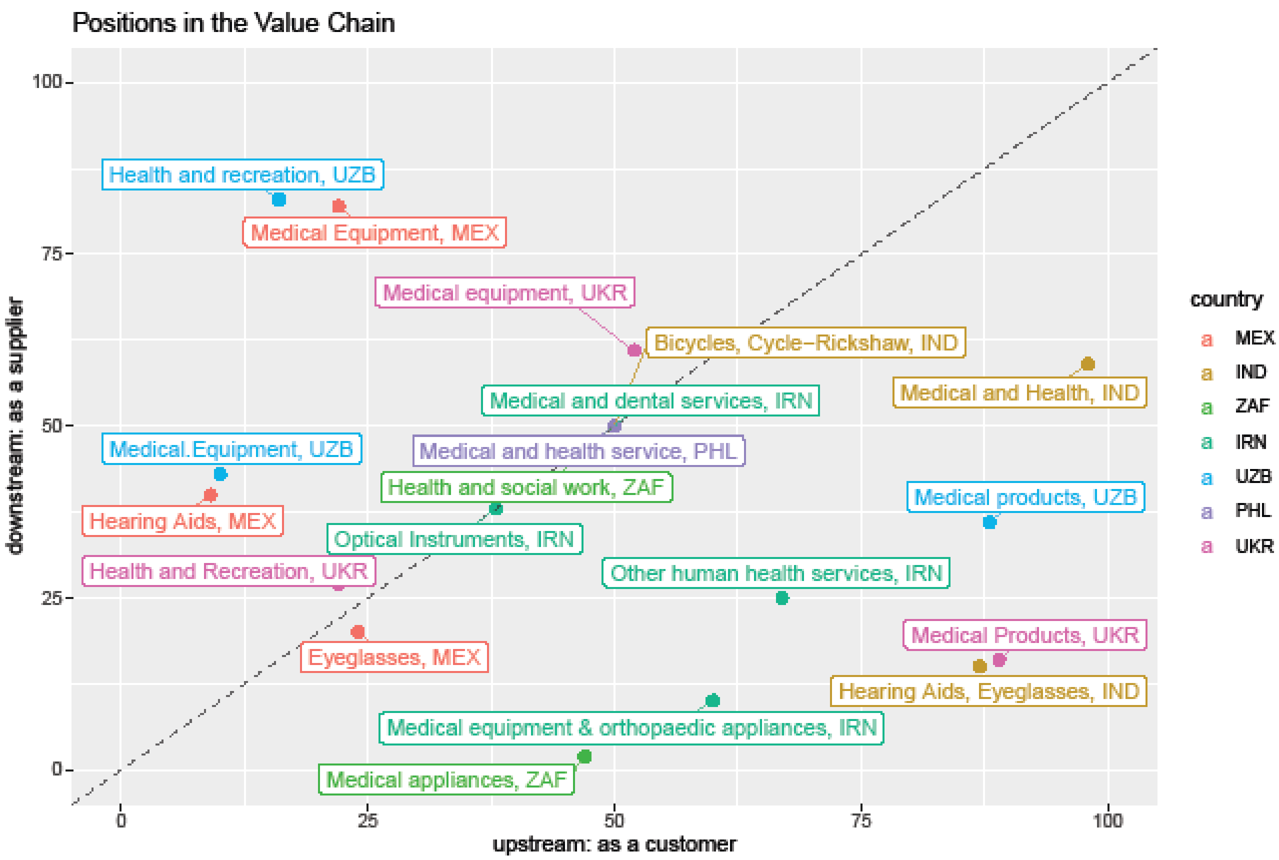
Source: Authors' own illustration

In particular, the in-degree and out-degree of a node correspond to the direct backward and forward linkages in production of a particular industry, as characterised by the aij coefficient. In a similar direction, eigenvector centrality is an extension of degree centrality that, instead of just awarding one point for every network neighbour a node has, awards a number of points proportional to the centrality scores of the neighbours. Hence, eigenvector centrality captures the relevance of a particular node within the whole structure of a network much better. Finally, the measure of Katz centrality xi works better in directed networks like input-output tables and bears a strong similarity to the standard Leontief model:

$$x_i = \alpha \sum_j A_{ij} x_j + \beta \vec{1} \tag{10}$$

where α and β are positive parameters and $\vec{1}$ is the uniform vector (1,1,...,1). Parameter α governs the balance between the eigenvector centrality term and the constant term β. Comparing the measure of Katz centrality with the standard Leontief model, one notes that β plays the role of final demand, while eigenvector centrality relates to the demand for intermediate goods. In sum, while computing the output multipliers for each sector, one is also measuring the centrality and thus relevance of this sector within the whole production ecosystem.

Figure 10: Relative position within the general structure of the economy, upstream vs downstream

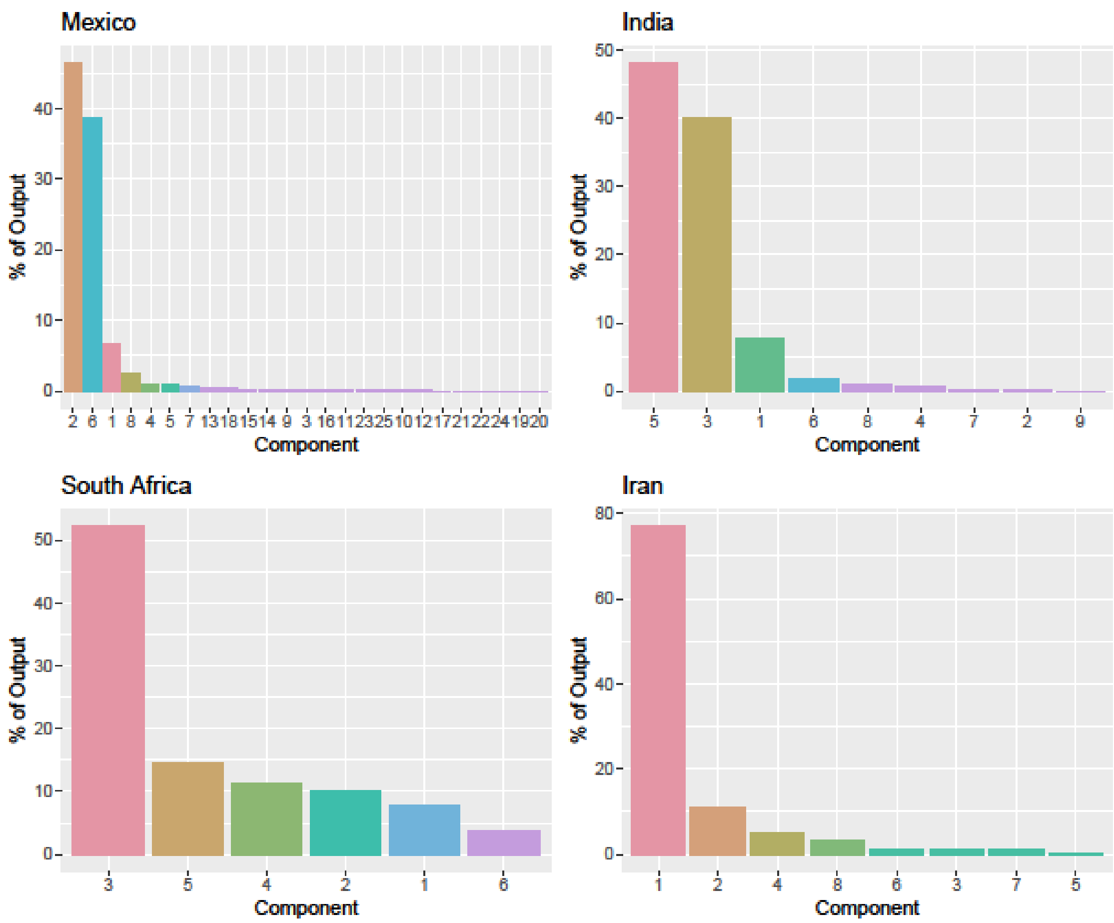


Source: Authors' own illustration

4. Data

The level of precision of the input-output table depends on the disaggregation by industrial sector: if it is sufficiently disaggregated, it will be able to show the industrial sectors that produce and sell assistive and health technologies. However, international databases such as the World Input-Output Database feature input-output tables with only 40-60 industrial sectors. Fortunately, the bureaus of statistics of many countries (including developing economies) offer highly disaggregated input-output tables. As well, the EORA database features a high level of disaggregation for specific developing economies, in particular Iran, Philippines, Ukraine and Uzbekistan (Lenzen et al 2012, 2013). For the present data analysis, input-output tables for Mexico[1], South Africa[2], India (Chadha et al 2020), Iran, Philippines, Ukraine and Uzbekistan (EORA, commodity view) are evaluated. These feature idiosyncratic lists of industries of differing numbers: 822, 52, 132, 148, 77, 121 and 131 sectors, respectively. Among those seven countries, one can directly identify up to 18 specific industries producing AT and health goods and services, such as eyeglasses, hearing aids, orthopedic devices or medical equipment (Table 1). In addition, the Indian industry producing bicycles and cycle-rickshaws, which can also be employed for the manufacturing of wheelchairs, is included in the analysis. Regarding the employment multipliers, only worker compensation data, rather than labour-hours employed, was found for Mexico, South Africa, Iran, Philippines, Ukraine and Uzbekistan, hence the employment multipliers computed are in terms of labour income.

Figure 11: Percentages of output for each community of the economic structures of selected countries (Mexico, which features the largest number of sectors, shows the closest to the typical exponential decay that these structures display)



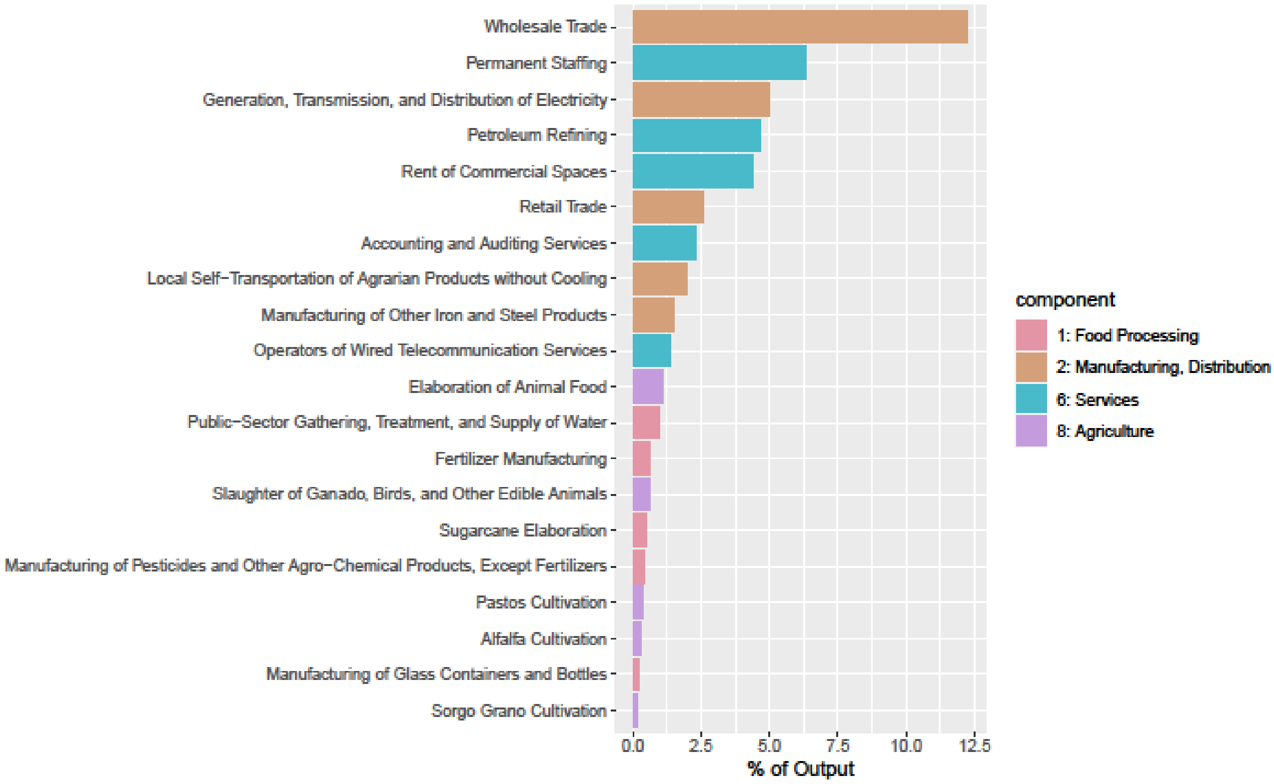
Source: Authors' own illustration

---

[1] Downloaded from INEGI, Sistema de Cuentas Nacionales de México.
[2] Downloaded from National Accounts – Statistics South Africa.

The current analysis allows light to be shed on the production structure of AT and health at many levels of economic development. Although they are all developing economies, the countries selected for the analysis feature very different levels of gross national income per capita within the middle range (between USD 1046 and USD 12,695 2022 World Bank classification): while Mexico and South Africa are considered upper-middle income countries, India, Iran, Philippines and the Ukraine are located within the lower-middle income range (Figure 7). For the sake of comparison, the average high-income country had USD 44,467.71 gross national income per capita, almost four times above the middle-income threshold.

Figure 12: Largest-output industries within the largest components of the Mexican economy (medical equipment and eyeglasses belong to the largest community (number 2), while hearing aids is located within the second largest component (number 6))



Source: Authors' own illustration

5. Results

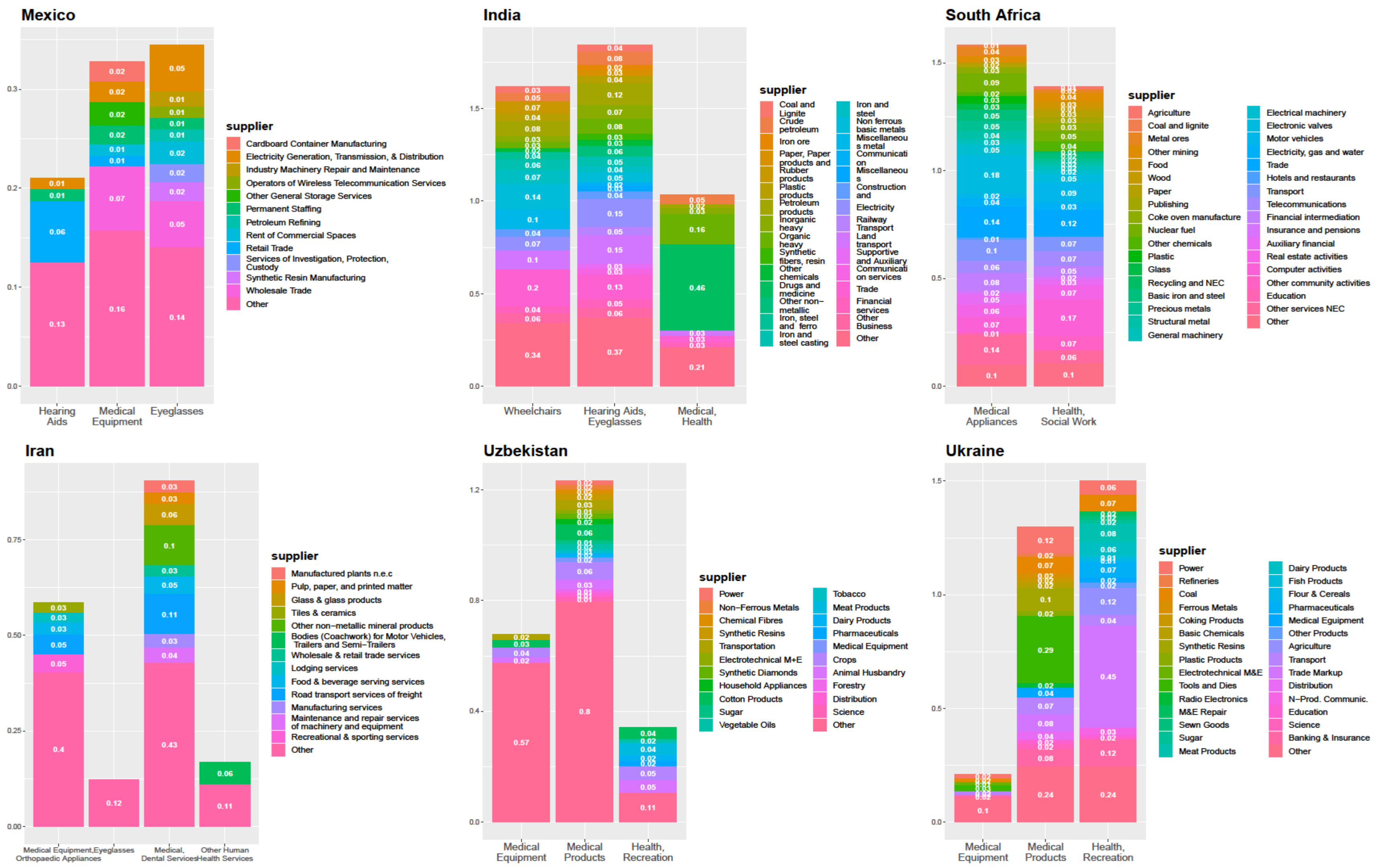
Figure 5 shows the aggregate Leontief multipliers of those 19 industries, both upstream (i.e. as a customer) and downstream (i.e. as a supplier), including the respective median value of each country for the sake of comparison. These values indicate the total returns of the spillover induced, upstream or downstream, on the economic structure by an increase in final demand, either in the form of fixed investment or consumption, by for-profit enterprise, government or non-profit organisations. Total output multipliers are much higher in the upstream channel (i.e. as a customer of intermediate goods) than downstream (i.e. as a supplier of intermediate goods): in the upstream channel, those returns can be as high as 3.07, as in the case of the Indian production of hearing aids and ophthalmic goods, which implies that for each dollar invested an extra 2.07 are gained, in addition to 2.67 for Indian wheelchairs, 2.62 for South African medical appliances or 2.41 for South African health and social work. Comparing the returns of the spillovers between both upstream and downstream directions, the former demand-driven channel will generally dominate over the latter supply-driven channel for almost all industries, except for Ukrainian medical equipment, Ukrainian health and recreation, and Iranian other human health services, which emphasises the positive demand-driven effects of investment over output (Figure 9). Upstream propagation of demand shocks induced by additional investment will dominate, spilling over the rest of the production ecosystem.

Conversely, the supply-led effects of investment on assistive and health technology will show a minor, second-order impact, benefiting final consumers and businesses using them as inputs by increasing productivity and thus decreasing their production costs.

Except for the Ukraine, the median upstream multiplier is larger than the median downstream multiplier, as it is in the case of AT and other health industries. This indicates that, in general, most industries of the economy occupy more downstream positions (i.e. as customers of intermediate goods) rather than upstream positions (i.e. as suppliers of intermediate goods). This result highlights the very hierarchical structure of input-output production networks composed of few clusters, with few industries acting as large, central, well-connected hubs (such as electricity production and distribution or wholesale trade) catering to a wide variety of small, peripheral sectors that constitute most of the economy, and display a low number of connections with low, yet close-to-average centrality, in line with similar empirical studies of the US and the OECD in this direction (Cerina et al 2015; Torres-González and Yang 2019).

This is further confirmed by the analysis of the community structure of the corresponding input-output networks via short random walks using the walk-trap algorithm (Pons and Latapy 2006). Figure 11 shows the percentage of output of each component or community for Mexico, India, South Africa and Iran. Figures 1, 2, 3, and 4 display the corresponding network visualisation, where nodes (i.e. industries) are coloured with the same palette as their community or component. Node sizes are proportional to their output, while the alpha transparency of the edges indicates the strength of the input-output linkage. The fact that the outputs of AT and health industries are not very large may lead to the conclusion that those sectors are unimportant or irrelevant. However, the analysis shows instead that these sectors are generally well-connected, in particular directly to the largest industries, and mostly located within the largest components of their respective economies (Figure 12). Hence, a demand shock of investment will reverberate immediately into the whole economy, with positive spillover effects in output, employment and productivity. However, this may quickly lead to supply bottlenecks on those central hubs, such as electricity generation and distribution, emphasising the pressing need for a coherent, consistent, mission-oriented industrial policy that pays special attention to those input-output dependencies. In short, the grand challenges of health for all and decarbonisation may need to be jointly addressed by policy-makers, since they cannot be extricated from each other. If industrial policy is not coherent in that respect, supply bottlenecks may multiply and inflation may ensue, as we are seeing today with the economic response to the COVID-19 pandemic.

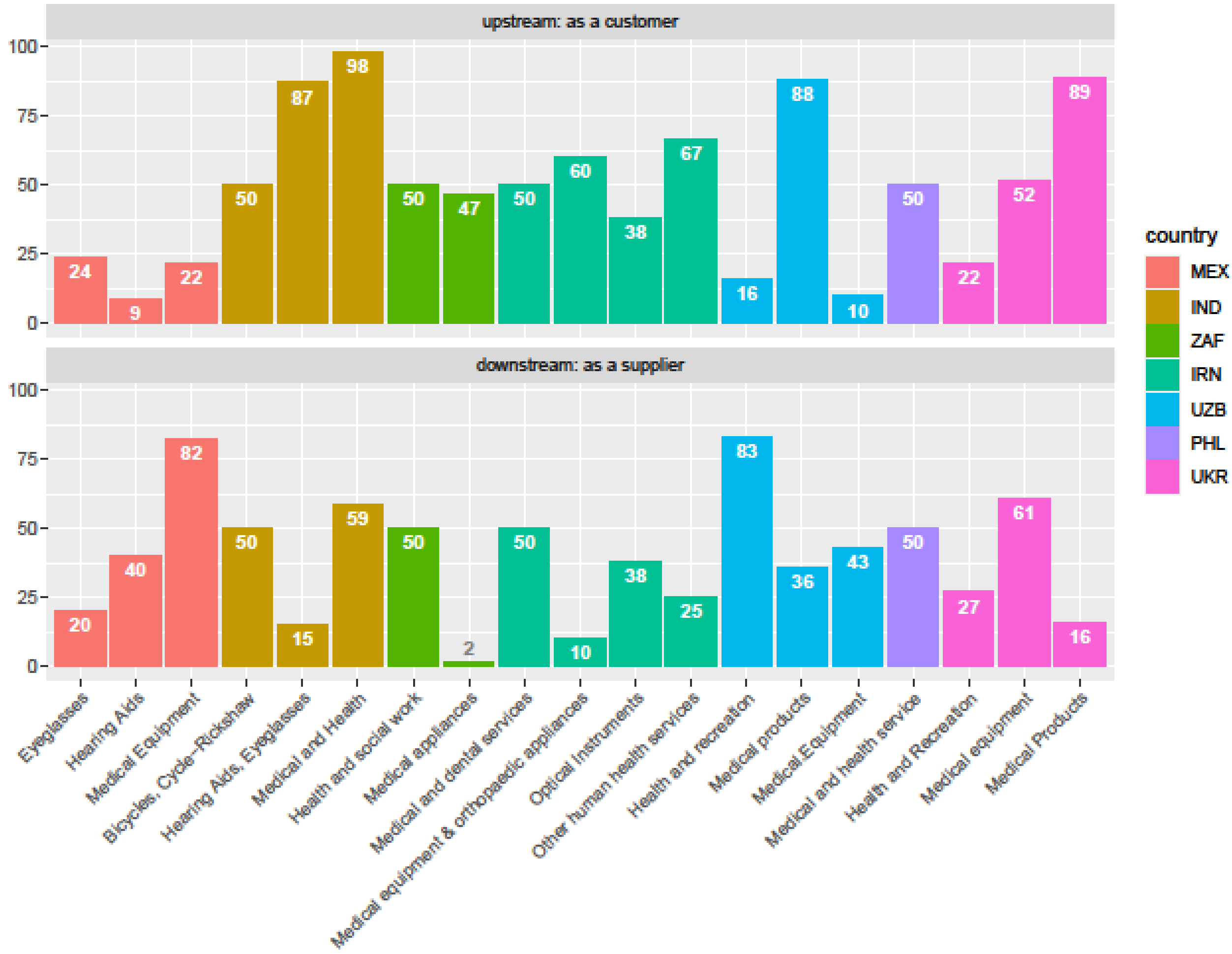
Figure 13: Leontief sector-by-sector upstream output multipliers



Source: Authors' own illustration

Rather than absolute values of the output multipliers, we may also be interested in the *relative position* of assistive technologies and health sectors within the general structure of the economy; that is, whether they are more or less upstream or downstream relative to other industries. In order to see this, we can compute the quantiles each multiplier occupies with respect to the general distribution of all industries (Figure 14) and plot the upstream values versus the downstream values (Figure 10). In Figure 14, values closer to 100 (0) imply they are at the top (bottom) of the distribution. Values around 50 indicate they are close to the average. The relevance of assistive and health technologies within their respective economies appears very uneven, with values ranging between nine and 98 in the upstream channel, highlighting, once again, in agreement with the insights of the mission-oriented framework and after a careful analysis of the market landscape, the need to implement policy interventions tailored to specific markets and industries rather than generic solutions.

Figure 14: Quantiles of aggregate Leontief output multipliers



Source: Authors' own illustration

Figure 8 shows the employment multipliers for the selected economies for which worker compensation data was available. Mexico shows employment multipliers for assistive technologies that are higher than the median value, except for medical equipment. South Africa features very high employment multipliers in the downstream direction, while median or below-median as a supplier in the upstream direction. For both countries, medical equipment shows low employment multipliers due to the high intensity of capital in that specific industry.

Further, measures of eigenvector centrality and Katz centrality are shown in Figure 15 (in particular, their respective quantiles for the sake of comparison with all other industries). Hearing aids in Mexico, hearings aids and eyeglasses in India, and health and social work in South Africa feature average centralities, while medical equipment in Mexico shows a high degree of centrality. In network theory, this hierarchical structure displays a rapidly decaying, fat-tailed distribution in both measures of degree and centrality, which may be exponential, power-law or log-normal (Gabaix 2009). Hence, the median value, rather than the average, gives a better notion of the typical industry, as featured in the figures. In this context, AT and health-related industries happen to be very similar to the majority of industries of the industrial ecosystem, with an average centrality and thus output and employment multipliers.

By disaggregating the Leontief output multipliers into the different upstream sectors supplying AT industries in their value chains, one can identify the upstream industries to receive a positive shock in demand, employment and productivity by consuming or investing in AT, both directly in the first year (direct) and in total (Leontief) terms (Figure 13). For Mexico, the most important sectors catering to AT industries are wholesale and retail grocery stores, as well as electricity production and distribution. For South Africa, the most important sectors in the upstream channel are electronic valves and trade for medical appliances, and computer activities for health and social work. In line with its very high output multipliers, the upstream Indian value chain of AT sectors is highly diversified, supplying from a wide range of industries.

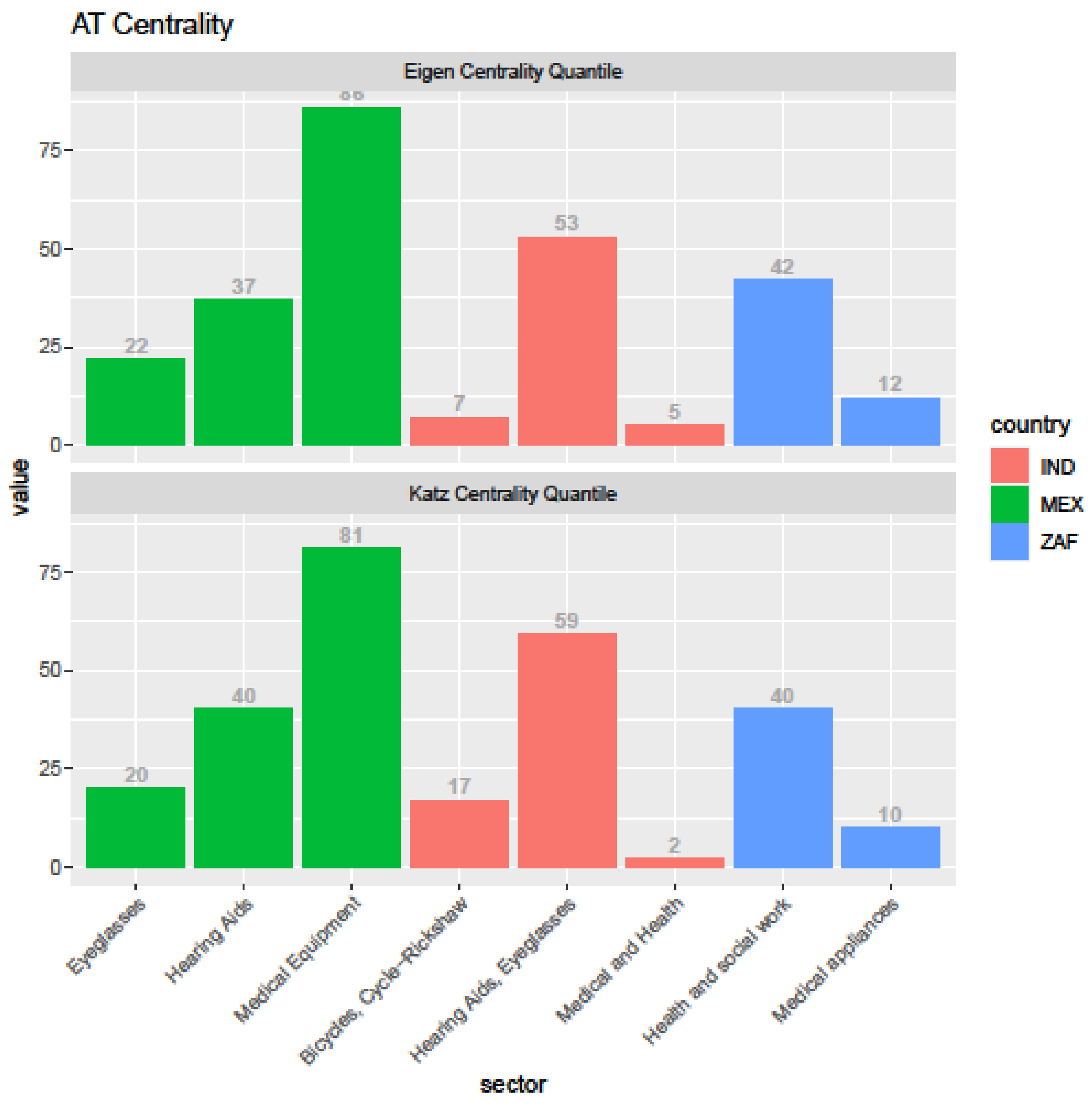
6. Conclusions

This paper shows how input-output analysis can be applied to characterise the network structure of the industrial ecosystem of specific sectors within the corresponding value chains, in particular AT and health, of lower-middle- and upper-middle-income economies (India, Iran, Mexico, Philippines, South Africa, Ukraine and Uzbekistan). Contrary to their conventional view as unimportant or peripheral, this paper shows that industries supplying such a fundamental, basic, common good like health are, in fact, as integral, well-connected and similar to most sectors of the economy, with network centrality, and output and employment multipliers, around the median. Just like most economic sectors within a fundamentally hierarchical general economic structure, these industries are located very much downstream within their value chains, directly catering to consumers, while supplying from a wide range of industries upstream, as their output multipliers are much higher in the upstream channel (i.e. as customers of intermediate goods) than in the downstream channel (i.e. as suppliers of intermediate goods).

In addition to their inarguable long-term economic and health benefits (ATscale 2020), the empirical findings of this paper support the direct short-term gains of large-scale, mission-oriented investment into the upstream channel of AT and health value chains, in agreement with the industrial policy logic at the basis of market shaping. Through the production channel of intermediate goods, the dynamic spillover effects of health investment over output and employment, as well as productivity through learning-by-doing, ripple immediately through almost the whole economy (between 75% and 99% of industries), with the most central and important industries within the economic structure first. This dynamic process not only shifts the rate of economic growth, but also its direction towards addressing the grand challenge of health for all that society critically faces today.

Last but not least, the findings of this paper also emphasise the pressing need to develop a coherent, consistent industrial strategy that includes the grand challenge of the low-carbon transition and that is specifically tailored to each industry providing health for all, rather than implementing generic industrial policies that may lead to undesirable side-effects, such as supply bottlenecks, protracted inflation and an eventual reduction in living standards.

Figure 15: Quantiles of AT centrality



Source: Authors' own illustration

References

Acemoglu, D., Carvalho, V. M., Ozdaglar, A. and Tahbaz-Salehi, A. (2012). The network origins of aggregate fluctuations. *Econometrica*, 80(5):1977–2016.

Albala, S., Holloway, C., Austin, V. and Kattel, R. (2021). *New Economics of Assistive Technology: A Call for a Missions Approach*. Working Paper 2021/4, UCL Institute for Innovation and Public Purpose. Available at: https://www.ucl.ac.uk/bartlett/public-purpose/sites/public-purpose/files/iipp_2021-04_at2030_missions_22_jan.pdf

Albala, S., Holloway, C., MacLachlan, M., Baines, D., Walker, J., Austin, V. et al (2019). *Capturing and Creating Value in the Assistive Technologies Landscape through a Mission-oriented Approach: A New Research and Policy Agenda*. Working Paper 2019/8, AT2030.

Alchian, A. A. (1950). Uncertainty, evolution and economic theory. *Journal of Political Economy*, 58(3):211–221.

Alesina, A. and Ardagna, S. (2010). Large changes in fiscal policy: taxes versus spending. *Tax policy and the economy*, 24(1):35–68.

Allas, T. (2014). Why a fundamental shift in innovation policy is necessary. In Mazzucato, M. and Penna, C., eds., *Mission-oriented Finance for Innovation*. Policy Network.

Andrich, R., Ferrario, M. and Moi, M. (1998). A model of cost-outcome analysis for assistive technology. *Disability and rehabilitation*, 20(1):1–24.

Arthur, W. B. (1999). Complexity and the economy. *Science*, 284(5411):107–109.

Arthur, W. B. (2014). *Complexity and the Economy*. Oxford University Press.

Arthur, W. B., Durlauf, S. N. and Lane, D. A. (1997). *The Economy as an Evolving Complex System II*, volume 27. Addison-Wesley Reading, MA.

Arthur, W. B. et al (1994). *Increasing Returns and Path Dependence in the Economy*. University of Michigan Press.

ATscale (2020). The Case for Investing in Assistive Technology. Technical Report 2020/11, ATscale.

Becker, M. C., Knudsen, T. and March, J. G. (2006). Schumpeter, Winter and the sources of novelty. *Industrial and Corporate Change*, 15(2):353–371.

Beinhocker, E. D. (2006). *The Origin of Wealth: Evolution, Complexity and the Radical Remaking of Economics*. Harvard Business Press.

Blanchard, O. J. and Leigh, D. (2013). Growth forecast errors and fiscal multipliers. *American Economic Review*, 103(3):117–20.

Blöchl, F., Theis, F. J., Vega-Redondo, F. and Fisher, E. O. (2011). Vertex centralities in input-output networks reveal the structure of modern economies. *Physical Review E*, 83(4):046127.

Boggs, D., Polack, S., Kuper, H. and Foster, A. (2021). Shifting the focus to functioning: essential for achieving sustainable development goal 3, inclusive universal health coverage and supporting COVID-19 survivors. *Global Health Action*, 14(1):1903214.

Carvalho, V. M. (2014). From micro to macro via production networks. *The Journal of Economic Perspectives*, 28(4):23–47.

Cerina, F., Zhu, Z., Chessa, A. and Riccaboni, M. (2015). World input-output network. *PloS one*, 10(7):e0134025.

Chadha, R., Saluja, M. and Sivamani, G. (2020). *Input Output Transactions Table: India 2015-16*. Working Paper 2020/1, Brookings India.

Deepak, S. (2019). Assistive technology capacity assessment survey in Mongolia. Technical report, GDI Hub, UK. Available at: https://at2030.org/static/at2030_core/outputs/2019_ATA-C_Survey_Mongolia_Report_Final.pdf

Deleidi, M., Mazzucato, M. and Semieniuk, G. (2020). Neither crowding in nor out: public direct investment mobilising private investment into renewable electricity projects. *Energy Policy*, pp. 111–195.

Deleidi, M., Meloni, W. P., Stirati, A. et al. (2018). Structural change, labour productivity and the Kaldor-Verdoorn law: evidence from European countries. Technical report, Department of Economics, University Roma Tre.

Dosi, G., Fagiolo, G., Aversi, R., Meacci, M. and Olivetti, C. (1999). Cognitive processes, social adaptation and innovation in consumption patterns: from stylized facts to demand theory. *Economic Organizations and Economic Knowledge: Essays in Honour of Brian Loasby*. Cheltenham, Edward Elgar.

Drummond, M., Brandt, A., Luce, B. and Rovira, J. (1993). Standardizing economic evaluation methodologies in health care. *International Journal of Technology Assessment in Health Care*, 9(1):26–36.

Drummond, M. F., Sculpher, M. J., Claxton, K., Stoddart, G. L. and Torrance, G. W. (2015). *Methods for the Economic Evaluation of Health Care Programmes*. Oxford University Press.

Durlauf, S. N. (1993). Nonergodic economic growth. *The Review of Economic Studies*, 60(2):349–366.

Foerster, A. and Choi, J. (2017). The changing input-output network structure of the US economy. *Economic Review (Kansas City)*, 102(2):23–50.

Foley, D. (2005). Complex and chaotic dynamics in economics. In Lines, M., ed., *Nonlinear Dynamical Systems in Economics*, pp. 27–66. Springer Vienna.

Foley, D. K. (2003). *Unholy Trinity: Labor, Capital and Land in the New Economy*. Routledge.

Forrester, J. W. (1970). Urban dynamics. *IMR; Industrial Management Review (pre-1986)*, 11(3):67.

Forrester, J. W. (1971). *World Dynamics*. Wright-Allen Press.

Forrester, J. W. (1997). Industrial dynamics. *Journal of the Operational Research Society*, 48(10):1037–1041.

Friedman, B. M. (1978). Crowding out or crowding in? Economic consequences of financing government deficits. *Brookings Papers on Economic Activity*, 1978(3):593–641.

Fuhrer, M. J. (2001). Assistive technology outcomes research: challenges met and yet unmet. *American Journal of Physical Medicine & Rehabilitation*, 80(7):528–535.

Gabaix, X. (2009). Power laws in economics and finance. *Annual Review of Economics*, 1(1):255–294.

Grossman, G. M. and Helpman, E. (1993). *Innovation and Growth in the Global Economy*. MIT Press.

Herlin, H. and Pazirandeh, A. (2012). Nonprofit organizations shaping the market of supplies. *International Journal of Production Economics*, 139(2):411–421.

Hirschman, A. O. (1958). *The Strategy of Economic Development*. Yale University Press.

Izquierdo Peinado, M., Moral Benito, E. and Prades Illanes, E. (2019). Propagation of sector-specific shocks within Spain and other countries. *Documentos de trabajo/Banco de Espana 1928*.

Kahn, R. F. (1931). The relation of home investment to unemployment. *The Economic Journal*, 41(162):173–198.

Kaldor, N. (1970). The case for regional policies. *Scottish Journal of Political Economy*, 17(3):337–348.

Kattel, R., Mazzucato, M., Ryan-Collins, J. and Sharpe, S. (2018). *The Economics of Change: Policy and Appraisal for Missions, Market Shaping and Public Purpose*. Working Paper 2018/6, UCL Institute for Innovation and Public Purpose. Available at: https://www.ucl.ac.uk/bartlett/public-purpose/publications/2018/jul/economics-change-policy-and-appraisal-missions-market-shaping-and-public

Kejariwal, R., Kobayashi, E., Savage, M., Seghers, F., Bhosa, T., Fineberg, A. E., Goedde, B., Austin, V. and Holloway, C. (2019). *Hearing aids*. AT2030 product narrative, Clinton Health Access Initiative, ATscale and Global Disability Hub. Available at: https://at2030.org/pn-hearing-aids

Kelton, S. (2011). Limitations of the government budget constraint: users vs. issuers of the currency. *Panoeconomicus*, 58(1):57–66.

Keynes, J. M. (1936). *General Theory of Employment, Interest and Money*. Atlantic Publishers & Dist. Reprint 2006.

Krugman, P. (1991). Increasing returns and economic geography. *Journal of Political Economy*, 99(3):483– 499.

Krugman, P. (1998). What's new about the new economic geography? *Oxford Review of Economic Policy*, 14(2):7–17.

Lenzen, M., Kanemoto, K., Moran, D. and Geschke, A. (2012). Mapping the structure of the world economy. *Environmental science & technology*, 46(15):8374–8381.

Lenzen, M., Moran, D., Kanemoto, K. and Geschke, A. (2013). Building eora: a global multi-region input–output database at high country and sector resolution. *Economic Systems Research*, 25(1):20–49.

Leontief, W. (1966). *Input-output Economics*. Oxford University Press.

Lin, A. and Wilson, J. (2014). *Healthy Markets for Global Health: A Market Shaping Primer*. Working paper, Center for Accelerating Innovation and Impact, United States Agency for International Development (USAID). Available at: https://www.usaid.gov/sites/default/files/documents/1864/healthymarkets_primer.pdf

MacLachlan, M., McVeigh, J., Cooke, M., Ferri, D., Holloway, C., Austin, V. and Javadi, D. (2018). Intersections between systems thinking and market shaping for assistive technology: the SMART (systems market for assistive and related technologies) thinking matrix. *International Journal of Environmental Research and Public Health*, 15(12):2627.

Mazzucato, M. (2015). *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*. Anthem Press.

Mazzucato, M. (2018). Mission-oriented innovation policies: challenges and opportunities. *Industrial and Corporate Change*, 27(5):803–815.

Mazzucato, M. and Macfarlane, L. (2017). *Patient Strategic Finance: Opportunities for State Investment Banks in the UK*. Working Paper 2017/5, UCL Institute for Innovation and Public Purpose. Available at: https://www.ucl.ac.uk/bartlett/public-purpose/publications/2017/dec/patient-strategic-finance-opportunities-state-investment-banks-uk

McCombie, J., Pugno, M. and Soro, B. (2002). *Productivity Growth and Economic Performance: Essays on Verdoorn's Law*. Springer.

McCombie, J. S. and de Ridder, J. R. (1984). The Verdoorn law controversy: some new empirical evidence using US state data. *Oxford Economic Papers*, 36(2):268–284.

Meadows, D., Randers, J. and Meadows, D. (2004). *Limits to Growth: The 30-year Update*. Chelsea Green Publishing.

Miller, R. E. and Blair, P. D. (2009). *Input-output analysis: foundations and extensions*. Cambridge University Press.

Nelson, R. R. and Winter, S. G. (1974). Neoclassical vs. evolutionary theories of economic growth: critique and prospectus. *The Economic Journal*, 84(336):886–905.

Nelson, R. R. and Winter, S. G. (1978). Forces generating and limiting concentration under Schumpeterian competition. *The Bell Journal of Economics*, pp. 524–548.

Nelson, R. R. and Winter, S. G. (2009). *An Evolutionary Theory of Economic Change*. Harvard University Press.

Newman, M. (2018). *Networks*. Oxford University Press.

Pasinetti, L. L. (1977). *Lectures on the Theory of Production*. Columbia University Press.

Patrick, M., McKinnon, I., Mishra, S., Gupta, S., Roy, P., Choudhury, U., Murugkar, K. and Raheja, G. (2021). *Inclusive Design and Accessibility in Varanasi, India*. Technical report, Global Disability Innovation Hub and partners for the UK Foreign, Commonwealth and Development Office. Available at: https://www.at2030.org/inclusive-infrastructure

Pons, P. and Latapy, M. (2006). Computing communities in large networks using random walks. *Journal of Graph Algorithms and Applications*, vol. 10, no. 2, pp. 191–218.

Ricciuti, R. (2003). Assessing Ricardian equivalence. *Journal of Economic Surveys*, 17(1):55–78.

Romer, P. M. (1986). Increasing returns and long-run growth. *Journal of Political Economy*, 94(5):1002–1037.

Savage, M., Afdhila, N., Seghers, F., Initiative, C. H. A., Frost, R. and Fineberg, A. E. (2019). *Wheelchairs*. AT2030 product narrative, Clinton Health Access Initiative, ATscale, and Global Disability Hub. Available at: https://at2030.org/pn-wheelchairs

Savage, M., Albala, S., Seghers, F., Kattel, R., Liao, C., Chaudron, M. and Afdhila, N. (2021). Applying market shaping approaches to increase access to assistive technology in low-and middle-income countries. *Assistive Technology*, 33(sup1):124–135.

Schumpeter, J. A. (1942). *Capitalism, Socialism and Democracy*. Routledge. Reprint 2013.

Seater, J. J. (1993). Ricardian equivalence. *Journal of Economic Literature*, 31(1):142–190.

Silverberg, G., Dosi, G. and Orsenigo, L. (1988). Innovation, diversity and diffusion: a self-organisation model. *The Economic Journal*, 98(393):1032–1054.

Simpson, L., Hamilton, F., Hassan, M., Rahman, A., Perry, K., Cotton, L., Bandukda, M., Thompson, N., Hajas, D. and Holloway, C. (2021). *Assistive Tech Impact Fund, the Story So Far: Insights from the First Cohort of AT Ventures*. Working Paper 2021/12, AT2030. Available at: https://at2030.org/static/at2030_core/outputs/Insight.pdf

Smith, E. M., Toro Hernandez, M. L., Ebuenyi, I. D., Syurina, E. V., Barbareschi, G., Best, K. L., Danemayer, J., Oldfrey, B., Ibrahim, N., Holloway, C. et al (2020). Assistive technology use and provision during COVID-19: results from a rapid global survey. *International Journal of Health Policy and Management*.

Thirlwall, A. P. (1979). The balance of payments constraint as an explanation of the international growth rate differences. *PSL Quarterly Review*, 32(128).

Torres-González, L. D. and Yang, J. (2019). The persistent statistical structure of the US input–output coefficient matrices: 1963–2007. *Economic Systems Research*, pp. 1–24.

Turner, G. M. (2008). A comparison of the limits to growth with 30 years of reality. *Global environmental change*, 18(3):397–411.

UNIDO. (2021). *The Future of Industrialization in a Post-pandemic World*. Industrial Development Report 2022, United Nations Industrial Development Organization.

Verdoorn, J. P. (1949). On the factors determining the growth of labor productivity. *Italian Economic Papers*, 2:59–68.

WHO. (2021). Governing health innovation for the common good. WHO Council on the Economics of Health for All, Brief No. 1 2021/11. Available at: https://www.who.int/publications/m/item/governing-health-innovation-for-the-common-good

ucl.ac.uk/iipp

@IIPP_UCL

UCL Institute for Innovation and Public Purpose
11 Montague Street, London, WC1B 5BP

General enquiries:
iipp-research@ucl.ac.uk
Tel: +44 (0)20 3108 6961